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# Thermal-Hydraulic Research Program at NRC


Dr. Jennifer Uhle

Director, Division of Systems Analysis

Office of Nuclear Regulatory Research

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# Contents

- NRC program goals
- Use of tools at NRC
- Status of code development efforts
- Future code development efforts
- Rod Bundle Heat Transfer Program
- Interfacial Area Transport Program
- Summary

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# NRC Program Goals

- RES mission
  - Provides NRC with technical advice and tools for identifying and resolving safety issues
  - Conducts independent experiments and analyses to support regulatory findings
  - Prepares the agency for the future by evaluating safety issues involving current and new technologies

- Thermal-Hydraulics program
  - This mission is accomplished, in part, by maintaining, developing and using TRACE
  - TRACE must be accurate, applicable to all NRC reviewed designs and easy to use and easy to maintain and develop
    - In-house development team

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# Use of TRACE at NRC

- TRACE is used by RES and the regulatory offices to:
  - Review licensee submitals (power uprates)
  - Review vendor designs
  - Review licensee T-H methods
  - Generate success criteria for NRC's PRAs
  - Investigate safety questions
    - sump clogging
    - CRDM and LHP breaks
  - Support rulemaking
    - Redefinition of large-break LOCA size
    - Fuel rod embrittlement criteria (boundary conditions)

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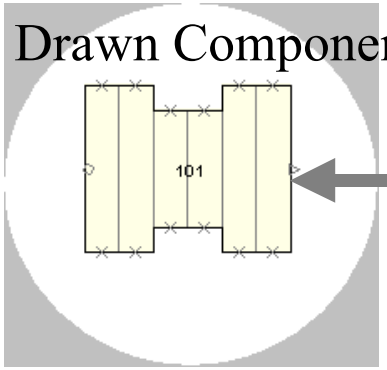
# Brief History of TRACE

- NRC consolidated the capabilities of TRAC-P, TRAC-B, RELAP, and RAMONA into a single computational platform
- Consolidation included modernization to make the code more extendible and easy to develop (TRAC-M)
- Initial assessment (500+ tests) performed identified some deficiencies
  - Conceptual problems
  - Separate effects tests
  - Integral effects tests
- Model improvement & error corrections made
  - Robustness
- Peer Review
- Assessment continues (matrix grows)
- Model development on-going
- Extension of assessment to new designs
- Input deck development for operating and new plants
  - ESBWR, EPR, US-APWR, 8 plant and containment types
  - TRAC-P, TRAC-B and RELAP5 input decks can be read by TRACE via SNAP

# SNAP Input Preparation

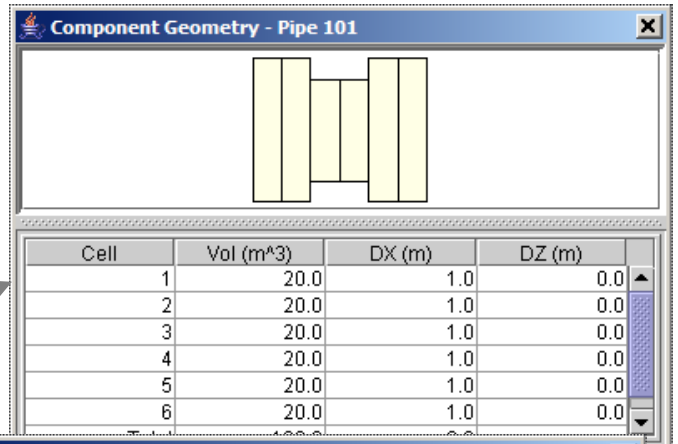
## Component Data Model

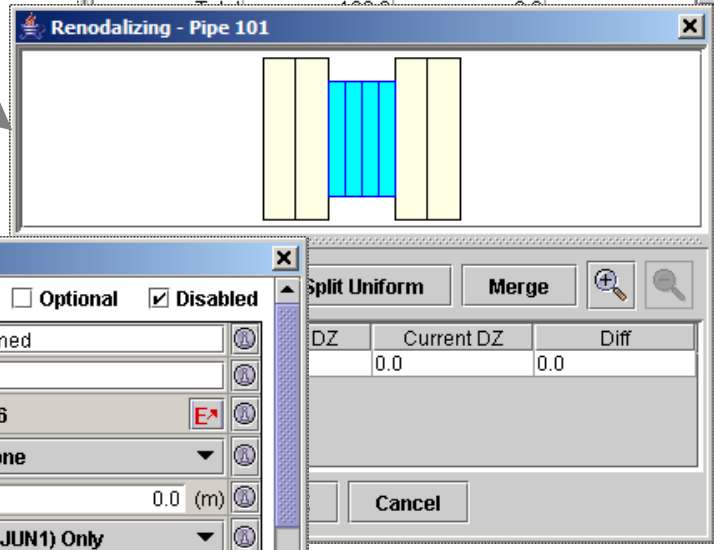
- All Component Data is Declared Private
- Views Implement a ComponentListener Interface
- Changes to Component Data are Automatically Reflected in all Views.

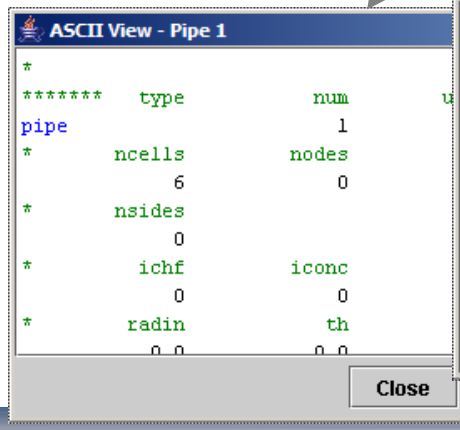


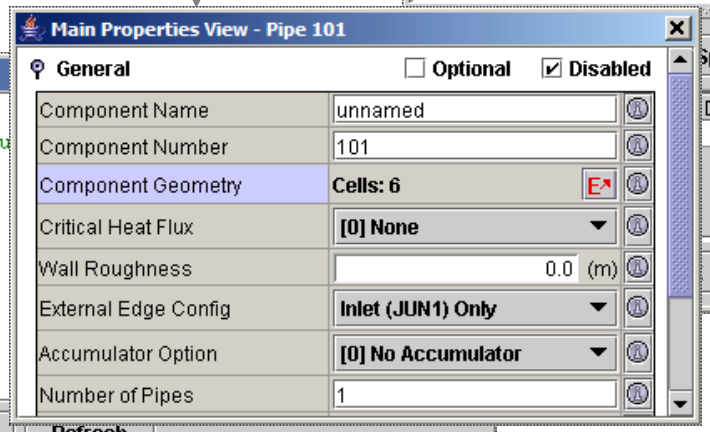

Data Model

Pipe 101 Data



# SNAP Output Visualization

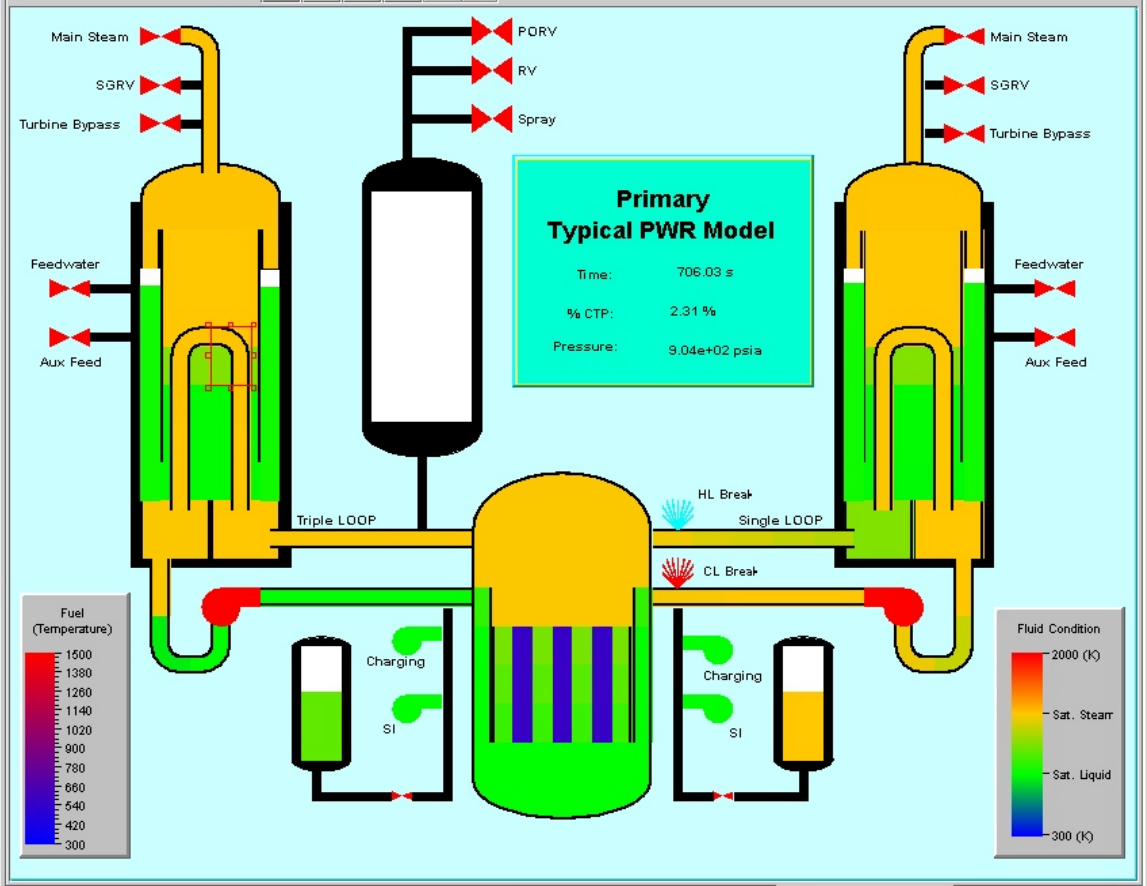
Model Editor 0.22.9

File Edit Tools Window Help

- RELAP5 models
  - **typpwr.med - (typpwr)**
- Animation models
  - **typpwr_anim.med - (Typical PWR)**
    - Model Options
    - Python Data Source
    - Data Sources [1]
    - Ranges [4]
    - Numerics [0]
    - Views [3]
      - Primary Full Plant
        - Fluid Condition Range
        - Temperature Range (Fuel)
      - Primary Vessel
      - Python Example

General ☐ Optional ☐ Disabled

| | |
|---|---|
| Data Source | Master: calcserv://local... |
| Range | Fluid Condition Range |
| Volume ID | 108040000 |
| X-Axis Alignment | 0.5 |
| Y-Axis Alignment | 0.5 |
| Background Color | 204,204,204 |
| Border | None |
| Command Menu | -not set- |
| Curved Fraction | 0.75 |
| Font | Dialog 8 (Dialog,,8) |
| Foreground Color | 0,0,0 |
| Opaque | ○ True ◉ False |
| Orientation | South-West |
| Outline Width | 3 |
| Pipe Width Fraction | 0.5 |
| ToolTip Text | volume-108040000 |




× Primary Hydraulic View × Broken Loop Steam Generator × Intact Loop Steam Generator × Primary Full Plant × Primary Vessel

Messages

- Disconnected from: Python Data Source
- Disconnected from: Master: calcserv://localhost/Local/LR5_308110537
- Connected to: Master: calcserv://localhost/Local/LR5_308110537
- Connected to: Python Data Source

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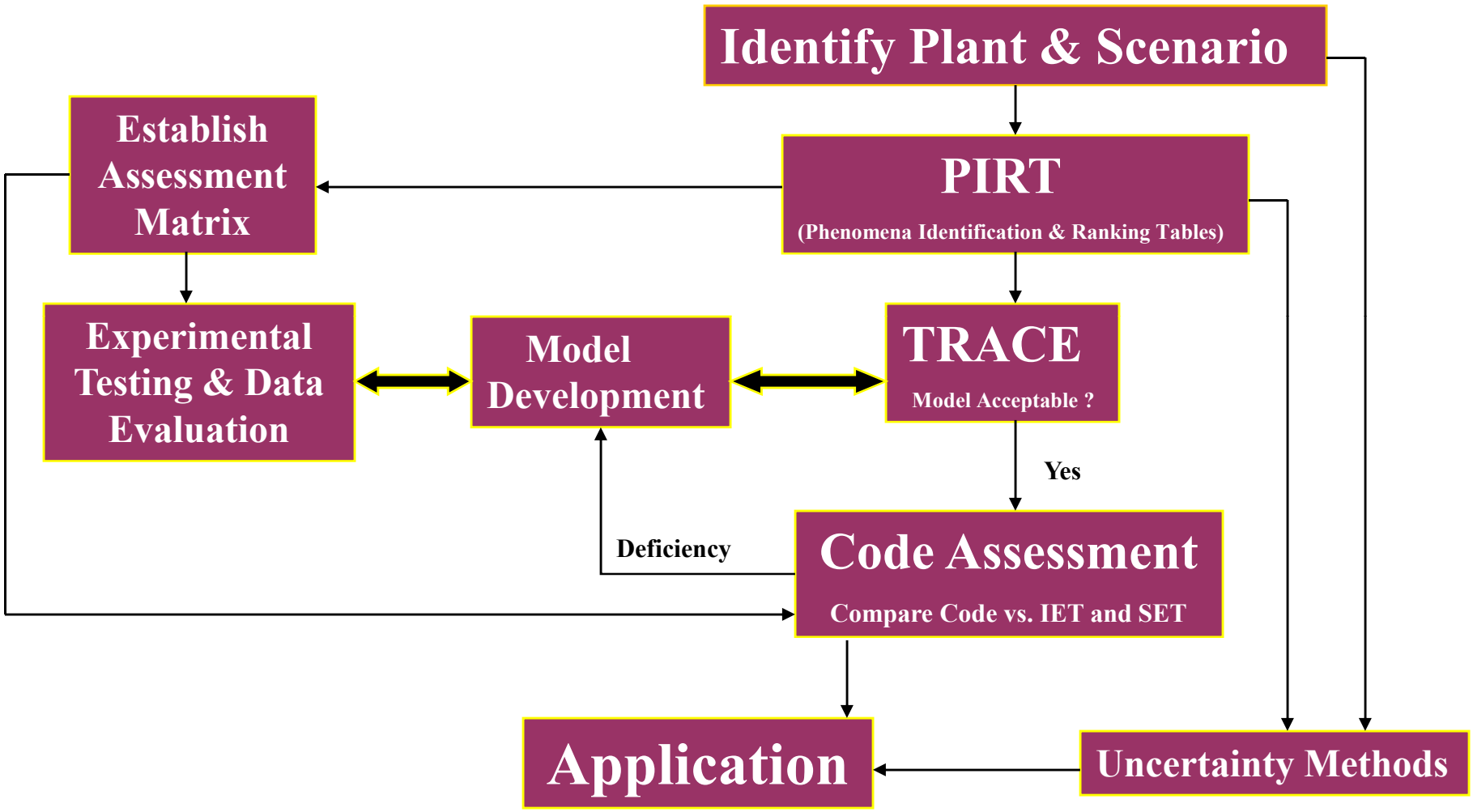
# TRACE Development / Assessment



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# T/H Assessment Tests

## Separate Effects Tests: Phenomena

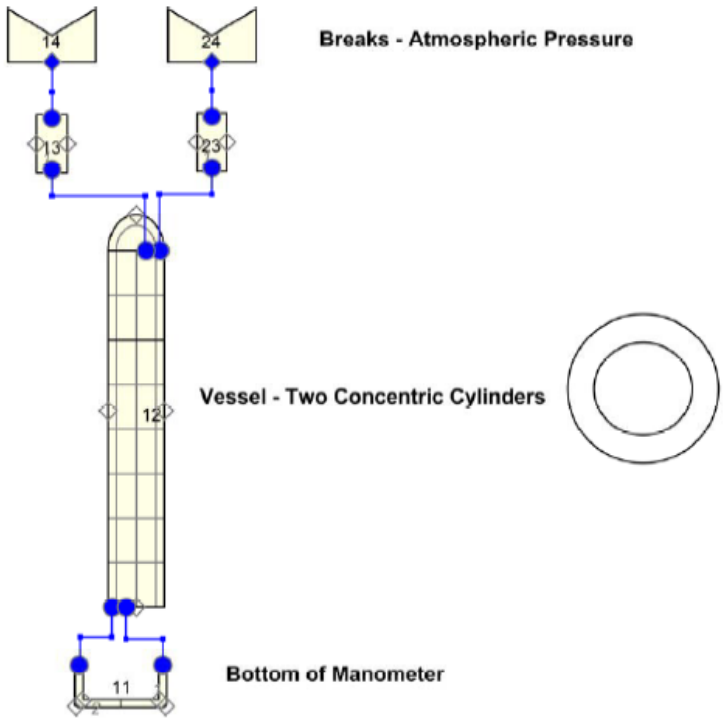
ANL Nat. Circ. Loop
Dehbi Condensation
CISE Adiabatic Tube
FRIGG; 36 rods
RBHT ; 45 rods
THETIS: 61 rods
THTF; 64 rods
FLECHT ; 98 rods
FLECHT-Skewed; 108 rods
FLECHT-SEASET ; 161 rods
G-2 Bundle; 336 rods
MB-2 SG Tests
Marviken
UPTF 1:1

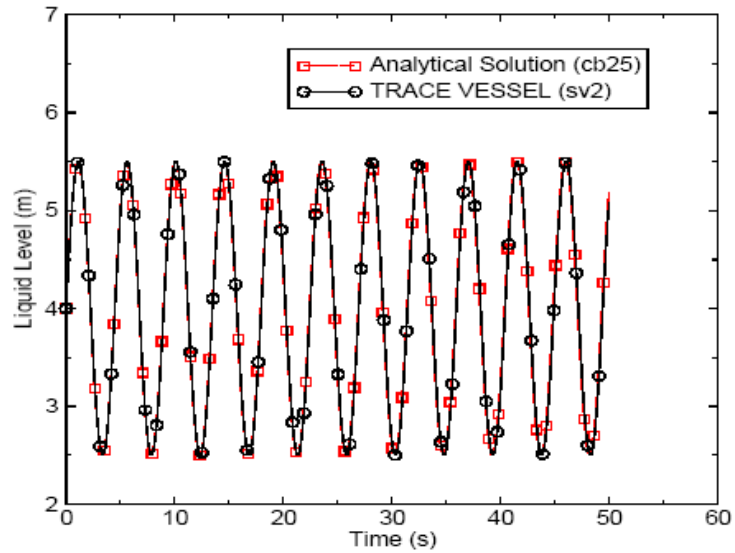
**Small Scale** → (Volume Scale) → **Full Scale**

Semiscale 1:1600
FIX-II; 1/777
FIST; 1/624
SPES 1:430
PUMA; 1/400
APEX 1:192
Bethsy 1:100
LOFT 1:50
ROSA 1:48
CCTF 1:25
SCTF 1:25
LWR 1:1

## Integral Effects Tests: System Interactions

# U-Tube Manometer Problem




**Known or well accepted solutions**

**Relatively simple models**

$$X(t) = \left(4.5 + \frac{2.1}{\sqrt{2\frac{g}{L}}}\sin\left(\sqrt{2\frac{g}{L}}t\right) + 0.002\cos\left(\sqrt{2\frac{g}{L}}t\right)\right)$$

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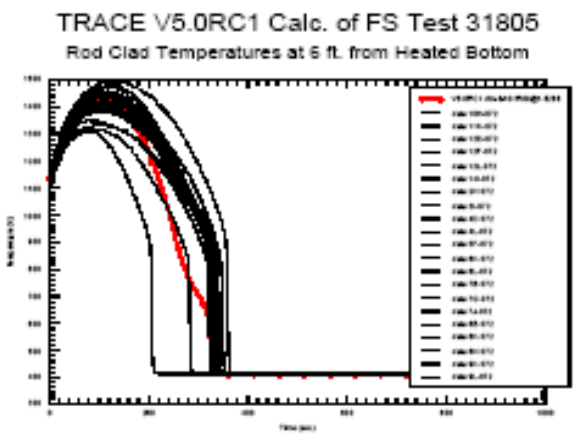
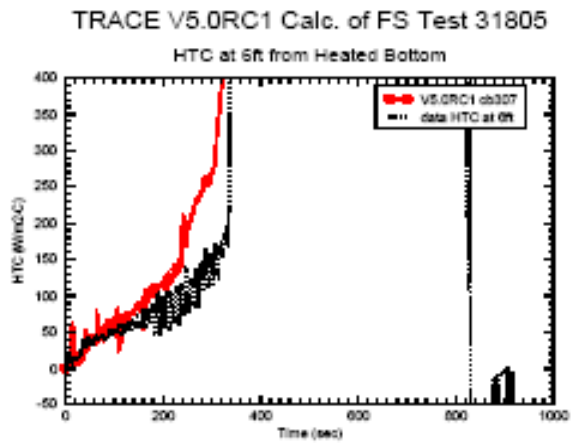
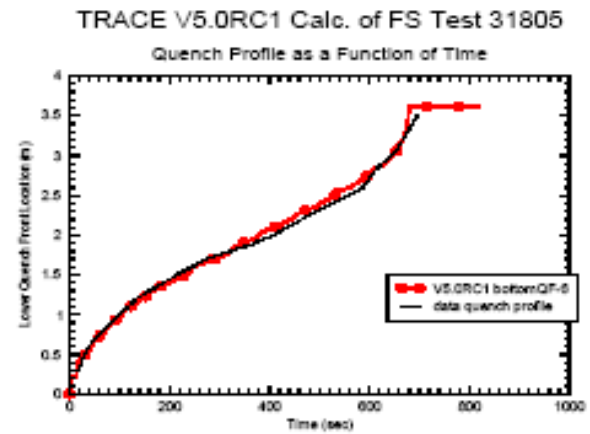
# TRACE V5RC1 Results

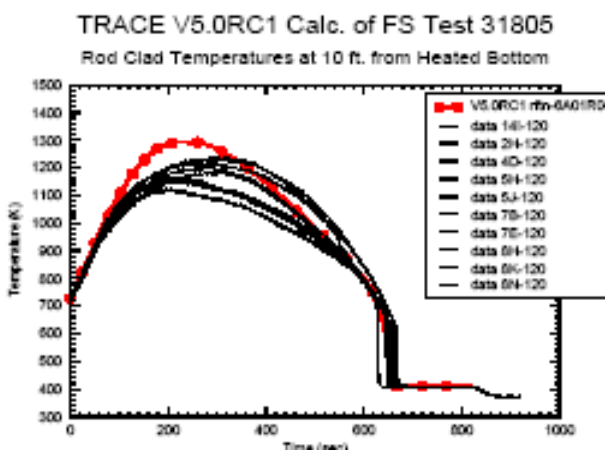
**FLECHT-SEASET Test 31805**

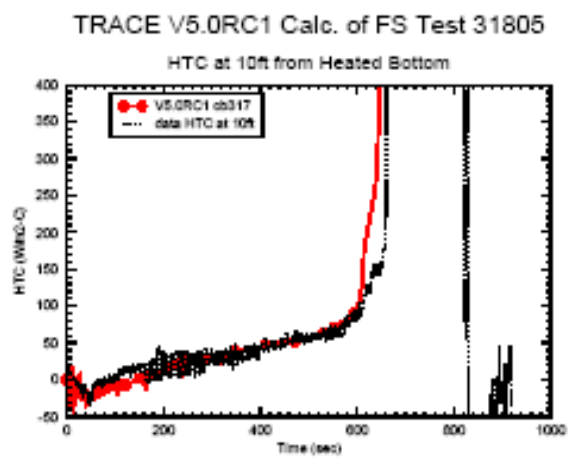


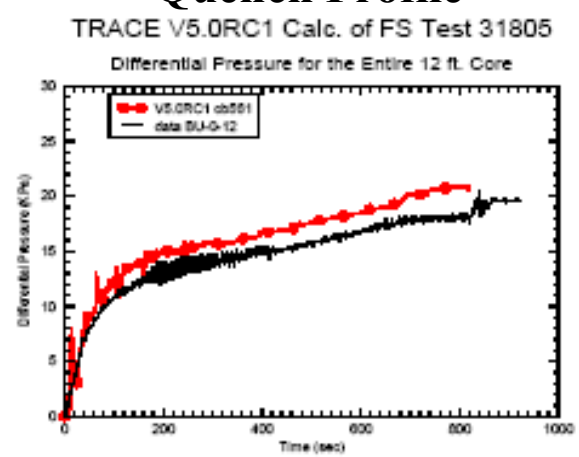




**Quench Profile**




**Cladding Temperatures** **Heat Transfer Coefficients** **Bundle ΔP**

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# PEER REVIEW

- Upon completion of documentation, we sponsored a peer review of TRACE
  - Provided critical review of conservation equations & numerical solution methods as applied, models and correlations, and special features within TRACE
  - Commented on the assessment matrix; breadth & range of conditions
  - Commented on the documentation; clarity, ease-of-use, thoroughness
- Peer review panel consisted of 4 experts in the field of thermal-hydraulic code development
  - Confirmed our development plans
  - Need to improve documentation

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# Future Development

- Upcoming development efforts intended to address deficiencies:
  - Droplet field & entrainment modeling
  - Spacer grid models
  - Interfacial drag model improvements
- Development of an uncertainty methodology
  - Using TRACE to range parameters
  - NRC/industry workshops on standard
- Advanced LWR design support

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# Rod Bundle Heat Transfer (RBHT)

- The RBHT Program is being conducted at Penn State Univ. to provide high quality experimental data for:
  - Reflood Thermal-Hydraulics
  - Steam Cooling Convective Heat Transfer
  - Two-Phase Void Distribution (Interfacial Drag)
  - Dispersed Droplet Film Boiling

- Each test series has provided information on spacer grid effects. Grid is a MVG similar to that in W 17x17 V5H fuel assembly.)

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# RBHT – Photo of Bundle and Instrumentation


Flow Housing Instrumentation

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# RBHT Findings

- Spacer grids can have a significant effect on rod bundle heat transfer due to
  - convective enhancement
  - grid rewet
  - entrained droplet break-up
- Video depicting phenomena
- TRACE can account for hydraulic losses due to spacer grids, but contains no models for convective enhancement, grid rewet, or droplet breakup
  - Assessment focused on these effects

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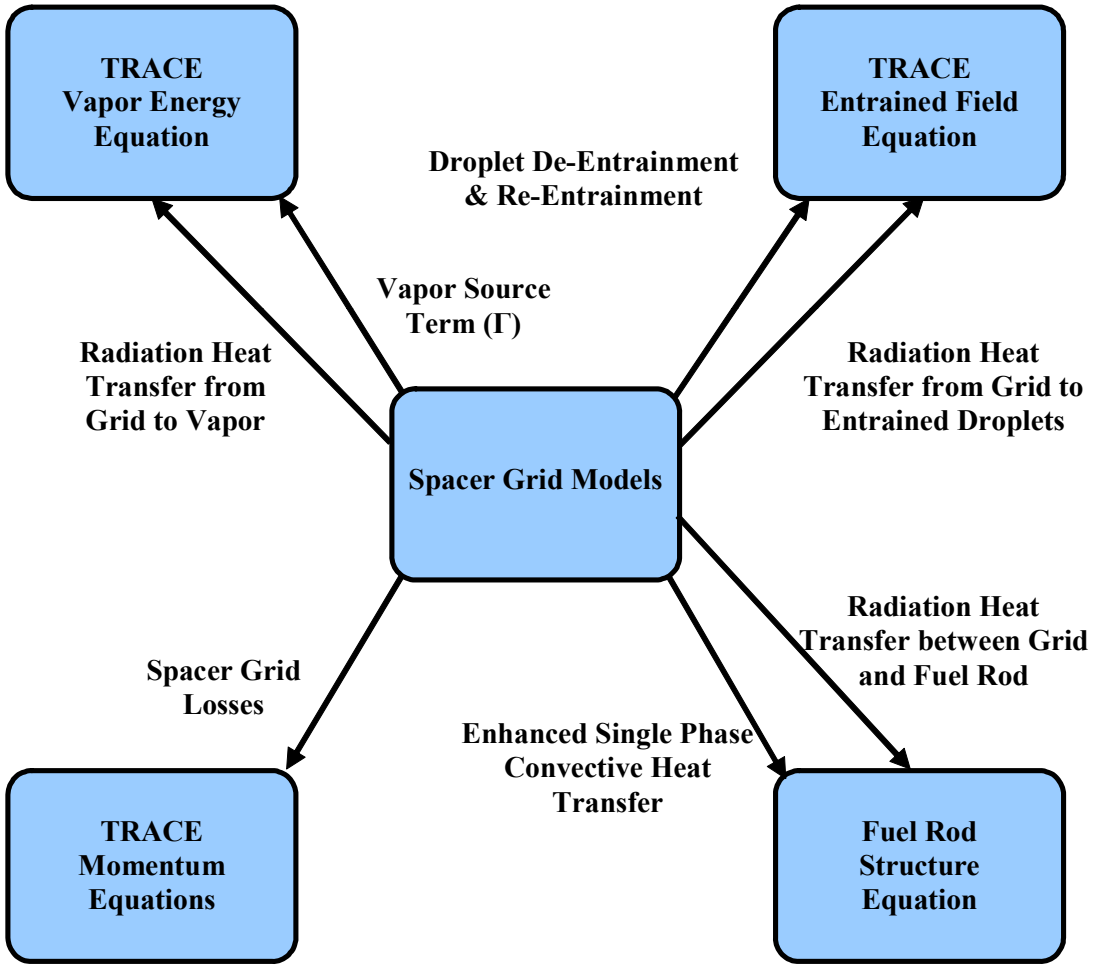
# Model Interactions in TRACE



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# Assessment Findings

- TRACE achieves correct energy balance, but misses the local convective enhancement effect of spacer grids
- Predicted HTC is typical of fully developed flow
- Lack of droplet breakup at spacer grids contributes to poor cooling at high elevations in tests where dispersed droplet flow is expected

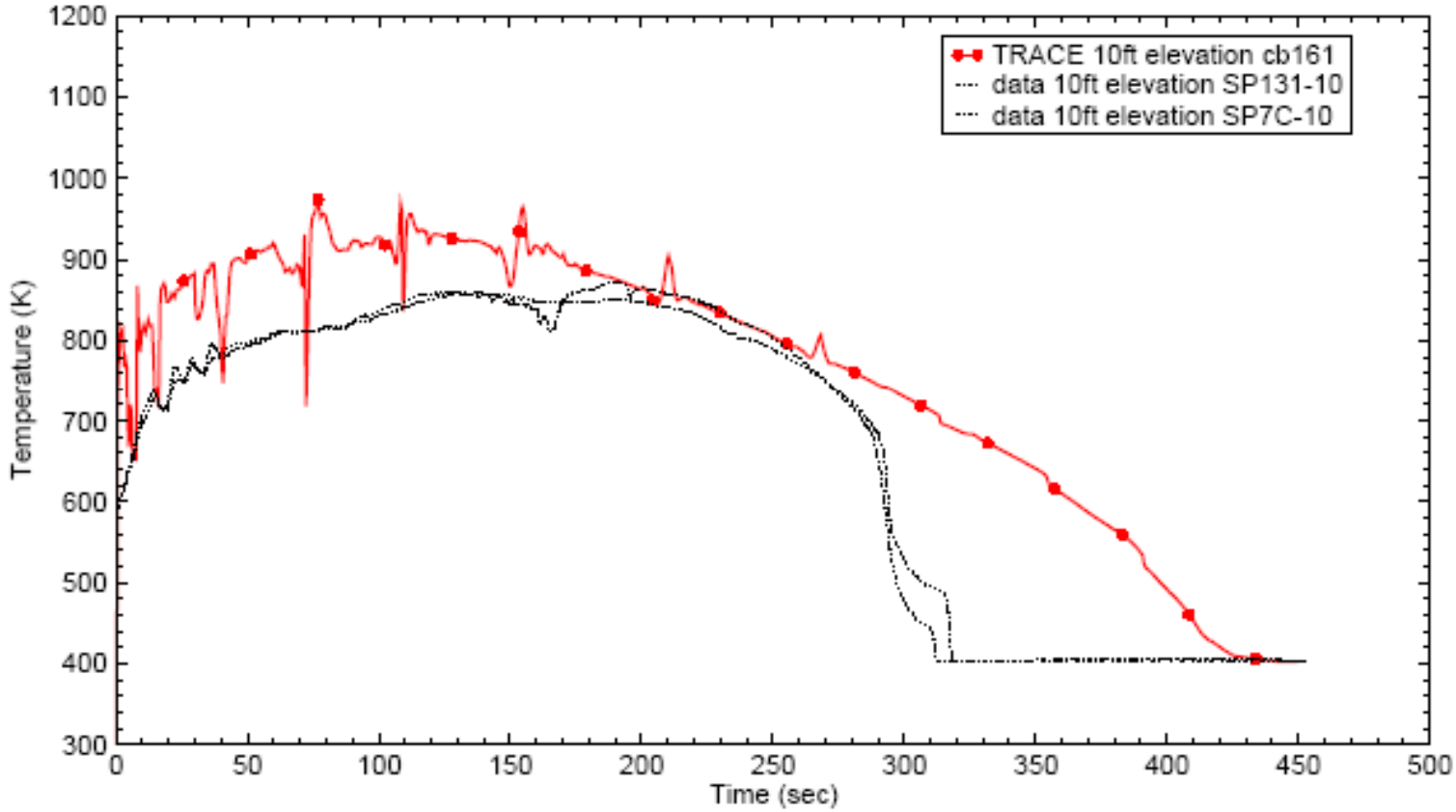


Figure B.7-74. Vapor Temperatures at 10 ft from Heated Bottom for Test 31203

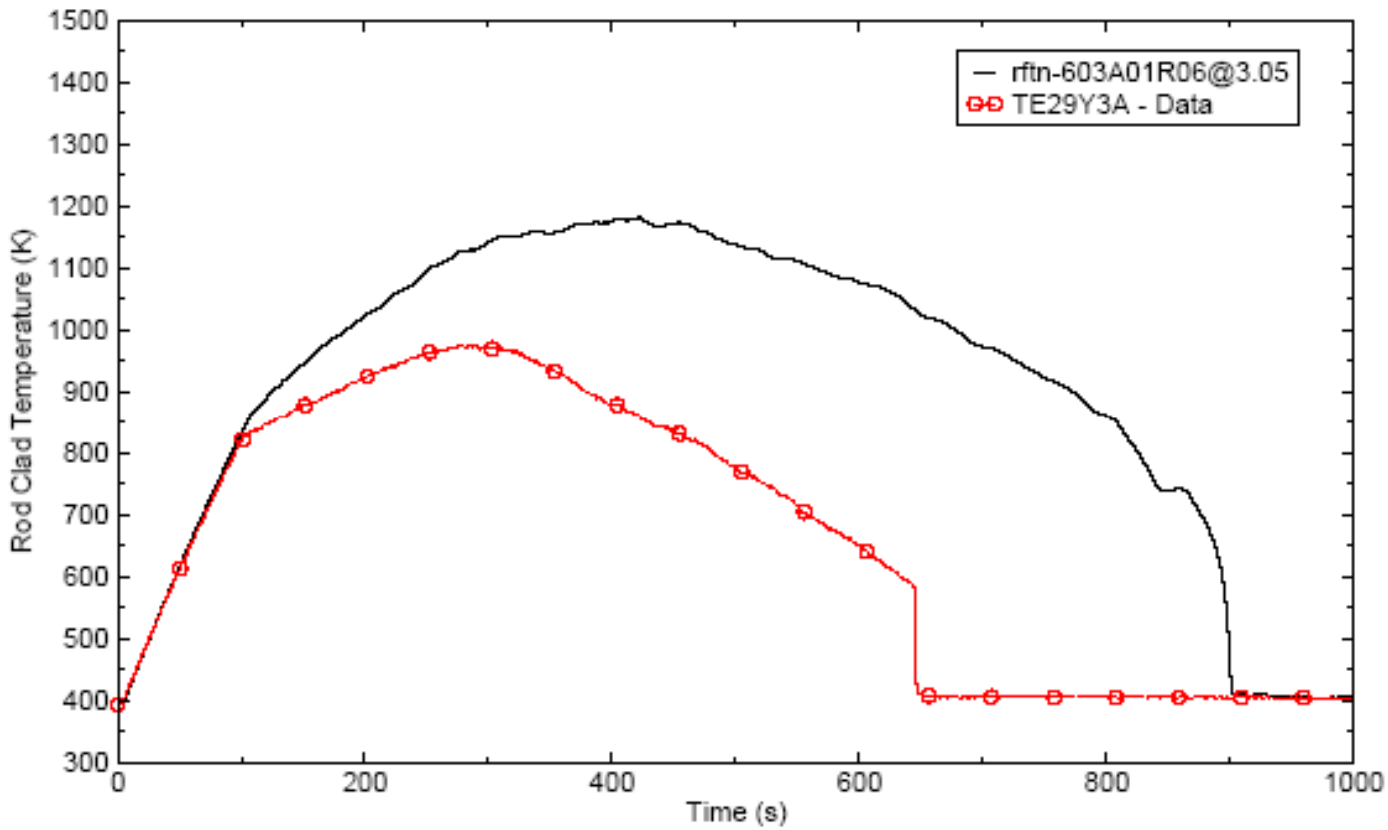


Figure C.2-38. Rod Clad Temperature Comparison at 3.05 Meters above the Bottom of the Heated Rods in the High Powered Region - Run 62.

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# TRACE Model Development

- Activate third field to serve as “entrained droplet field”
  - Entrainment
  - De-entrainment
- Spacer Grid T/H Models being incorporated:
  - Continuous Phase Convective Enhancement
  - Spacer Grid Pressure Loss Coefficients
  - Entrained Droplet Breakup
  - Spacer Grid Rewet

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# Limitations of Flow Regime Models

- Use flow regime maps to determine the value of interfacial area concentration
  - Flow regime maps were developed with data under fully-developed, steady-state conditions
    - Do not dynamically represent the changes in interfacial structure
  - Flow regime maps were typically developed from tube data
    - Not prototypic of more complex geometries, such as rod bundles or reactor piping systems
  - Instantaneous changes in flow regimes can lead to non-physical oscillations and can limit accuracy

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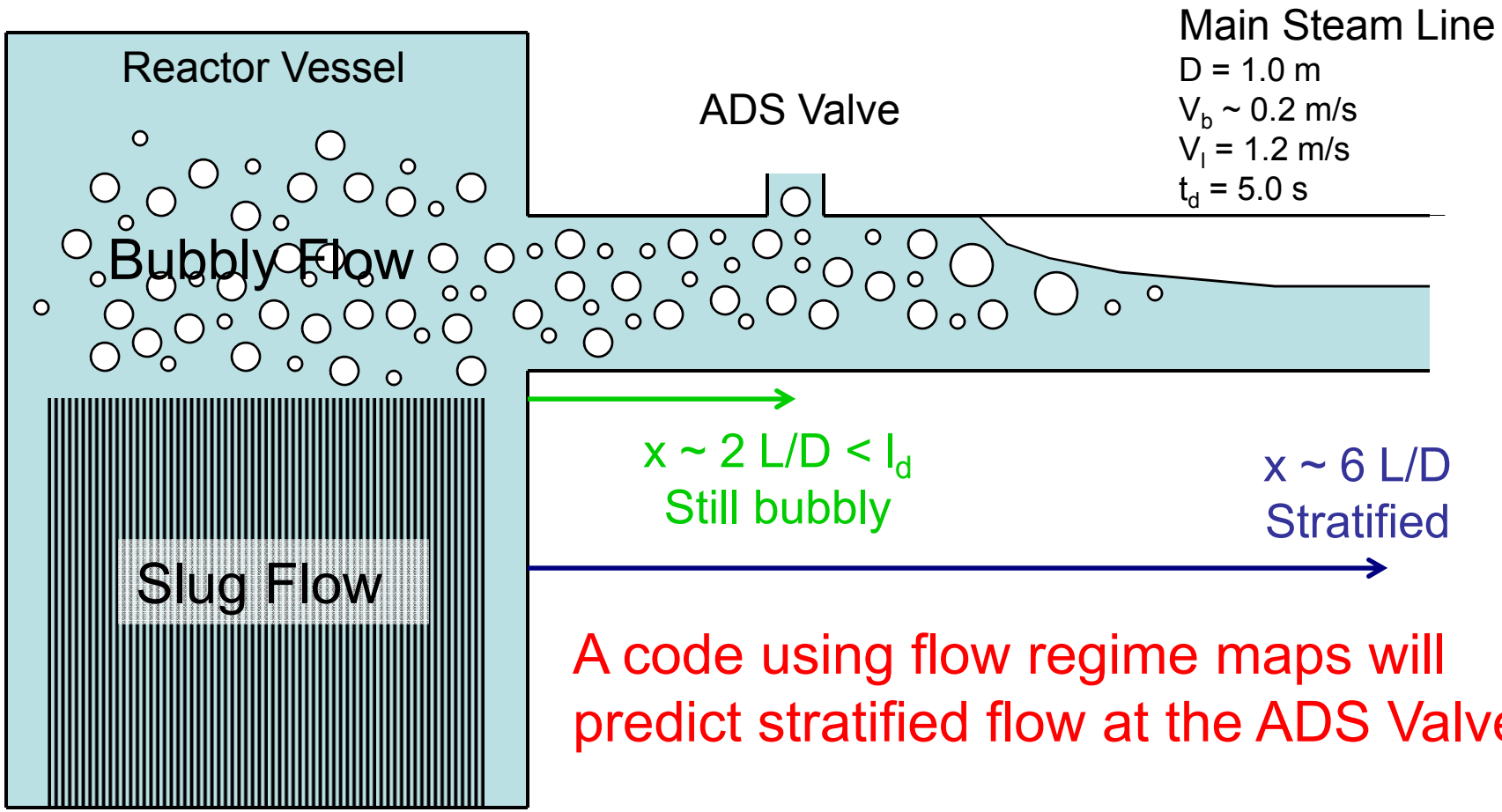
## Static Flow Regime Maps May Not Generate Conservative Results

### Example: ADS Discharge Line




A code using flow regime maps will predict stratified flow at the ADS Valve

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# NRC Sponsored IATE Research

- Experiments at the Thermal-Hydraulics Institute at Purdue University
  - Large Hydraulic Diameter Pipe Experiments
    - 6-in. (0.152 m) and 8-in. (0.203 m) vertical pipes
    - Exit pressures of 180 kPa and 280 kPa
    - Void fraction up to 80 percent
    - Mass flux up to 1000 $kg/m^2s$
  - Rod Bundle Experiments
    - 8x8 full size BWR rod bundle test section
      - Acrylic test section for atmospheric tests
      - Stainless steel test section for high pressure tests
    - Void fraction and grid loss database
  - Heated Annulus Experiments
    - 1.9 cm OD heater rod inside a 3.8 cm ID Pyrex or stainless steel tube
    - Pressures up to 10 bar

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# Prior IAT Research

- Adiabatic Experiments Near 1 bar
  - ½”, 2”, 4”, 6” ID Tube Data
- Adiabatic High Pressure Experiments
  - Annulus 1½” OD, ¾” ID (< 10 bar)
- 2” Adiabatic Horizontal Flow Data

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# Need for Additional IAT Data

- Data for Interfacial Area Change at Changes in Geometry
  - Contraction & Expansion
  - Elbow
  - Tank to Pipe with Direction Change
  - Pipe to Tank with Direction Change
  - Tee Junction
- Nucleation Effect
- Condensation Effect
- Rod Bundle
- Effect of Fluid Properties

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# Summary

- RES development of TRACE is aimed at providing a tool for resolution of safety issues and for independent assessment of licensee and vendor submittals

- Development is focused on resolving deficiencies in order of importance using PIRT insights
  - Grid spacer model
  - Loop seal clearing

- International collaboration (CAMP, bilateral agreements) contributes to this development